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The effects of soil treatment with DDT on the biology of a cultivated forest soil in the sub-humid tropics

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With 4 figures

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Contents

1. Introduction

It is now well established for temperate regions that the rate of disappearance of plant litter from the soil is related to the number of arthropods and earthworms in the litter and in the underlying soil (Crossley & Hoglund 1962; Edwards & Heath 1963). Feeding by earthworms and microarthropods in particular results in extensive incorporation of the litter into the soil through fragmentation and conversion to faeces, rendering it more readily available for further breakdown by microorganisms. DDT has been shown to have adverse effects on many elements of the soil fauna (Edwards & Thompson 1973; Cook et al. in prep.; Perfect et al. in prep.; Critchley et al. in prep.) and thus through its effect on the detritivores may influence the rate of breakdown of organic matter in the soil. Such effects have been demonstrated with aldrin, though not DDT in the temperate regions (Edwards 1965a).

This paper describes work carried out at the International Institute of Tropical Agriculture, Ibadan, Nigeria where DDT was incorporated directly into the soil prior to cultivation with cowpea, *Vigna unguiculata* (L.) Walp. The rate of breakdown of the pesticide and its effect on soil microarthropods and microflora, earthworm casting activity and the rate of decomposition of organic matter were monitored. The study was conducted as a supplement to work described by Perfect et al. (in prep.) in which the effects of DDT applied to the crop under an agricultural spraying regime were assessed, and was intended to give a short term indication of pesticide levels at which impact on the soil system could be anticipated.

2. Materials and methods

An area of regenerating secondary forest 35×30 m was cleared and ploughed in February 1974. Absence of DDT residues from the site was confirmed by analyses of soil samples by gas liquid chromatography. During the first of the two annual growing seasons (April—June), cowpea *Vigna unguiculata* variety *Prima* was planted to allow soil populations to stabilize partially prior to the establishment of the experiment in the second growing season (September—November) of 1974.

In July 1974 the site was subdivided into 16 plots each of 6.2 × 3.8 m arranged in a 4×4 grid with the plots separated by 1 m wide barrier strips planted with the grass *Paspalum notatum* FLUGGE. Four plots were randomly allocated to each of three DDT pesticide treatments while four remained untreated and served as controls.

After disk and harrow ploughing, DDT was applied to the soil directly over a range of concentrations to give levels of approximately 1, 10 and 100 $\mu g\ g^{-1}$ when incorporated into the top 150 mm of soil. These treatments are subsequently referred to as low, medium and high DDT treatments. The DDT was applied as a water-borne emulsion [trade name Didimac, ICI (Nigeria)] in equal volumes to all treated plots using watering cans and was mixed into the soil to a depth of 150 mm using a two stroke hand rotavator. An equal volume of water was incorporated into the control plots in the same manner. No further pesticide was applied.

The plots were then planted with cowpea following the method of cultivation described by PERFECT et al. (in prep.) and the crop harvested between 10 and 12 weeks after planting. The crop debris from the second 1974 planting remained on the plots during the dry season and was ploughed under in May 1975 to a depth of 150 mm. The plots were recultivated with cowpea which was slashed after 5 weeks and the crop debris ploughed in at a rate of 625 kg ha^{-1} to a depth of 150 mm, for a separate study to investigate the effects of soil contamination on the rate of disappearance of plant material incorporated into the soil. Since this time the plots have remained fallow.

Soil cores were taken from the treated plots 0, 2, 5, 10, 20, 40 and 80 days after DDT application to follow the fate of the pesticide. Further samples were taken in July 1975 (after ploughing) and in November 1976. On each occasion five 50 mm diameter soil cores were taken per plot to a depth of 300 mm. These were bulked for the 0—150 mm and 150—300 mm depths, subsamples being retained for subsequent extraction and analysis for DDT and related compounds by gas liquid chromatography. A more detailed study was carried out on one of the replicates of each DDT treatment at the beginning of the experiment, after 80 days and in May 1975. Ten cores were taken per plot and the 0—50 mm, 50—100 mm and 100—150 mm sections extracted individually together with two 150—300 mm sections.

Before harvest five plants were taken from each plot, the leaves, roots, stems, beans and husks bulked and retained for GLC analysis. The experimental procedures used for DDT extraction from both soil and vegetation together with details of the GLC analysis are fully documented by YEADON and PERFECT (in prep.).

Microarthropod populations were assessed by extraction from 50 mm diameter soil cores taken in August 1974, 15 days after pesticide application, and again in August 1975 and 1976. Five soil cores were taken per plot to depths of 0—50 mm in 1974 and 0—100 mm in 1975. The 0—100 mm cores were extracted in two 50 mm sections as were the eight cores per plot taken in 1976. Microarthropods were extracted using a modified MACFADYEN high gradient apparatus (PERFECT et al. in prep.) and identified to the major taxa.

Two types of earthworm casts are apparent in the Ibadan area, one turret shaped and compact, the other loose and granular, attributed by MADGE (1969) to *Hyperiodrilus africanus* and *Eudrilus eugeniae* respectively. Other species may also be involved but for this paper the two types of surface casting earthworms are subsequently referred to as *Hyperiodrilus* and *Eudrilus*. The area between two adjacent rows (0.6 m apart) extending the length of the plot was used as the sampling area. The sampling area in each plot was cleared of casts and the casts produced during the subsequent 24 hours were counted. Those of *Hyperiodrilus* were removed, dried and weighed.

The decomposition rate of buried leaf material enclosed in 1 mm mesh wire cylinders was investigated. The cylinders were 50 mm long and 50 mm in diameter, held at top and bottom by plastic caps. Each cylinder was filled with 5 g air dried *Hippocratea* sp. leaf material, this being the dominant woody species in the surrounding secondary thicket. Two days after soil treatment with DDT, 25 cylinders were buried at random positions to a depth of 50 mm in each plot. After 5, 10, 20, 40 and 80 days, five cylinders were removed from each plot and the fauna extracted using the Macfadyen extraction apparatus. The remaining litter was carefully removed, washed, dried at 60 °C and weighed to measure the extent of decomposition.

Estimates of fungal biomass were obtained from the leaf material in the cylinders collected after 5, 40 ond 80 days by the JONES and MOLLISON technique (1947).

A cellulose decomposition experiment was conducted using cellophane strips enclosed in nylon mesh bags placed on the soil surface. This is reported elsewhere (MOORE in prep.).

The data were analysed using two-way analysis of variance incorporating effects of treatment and time. Logarithmic transformations were used for all animal population data and plot totals were taken as the replicates.

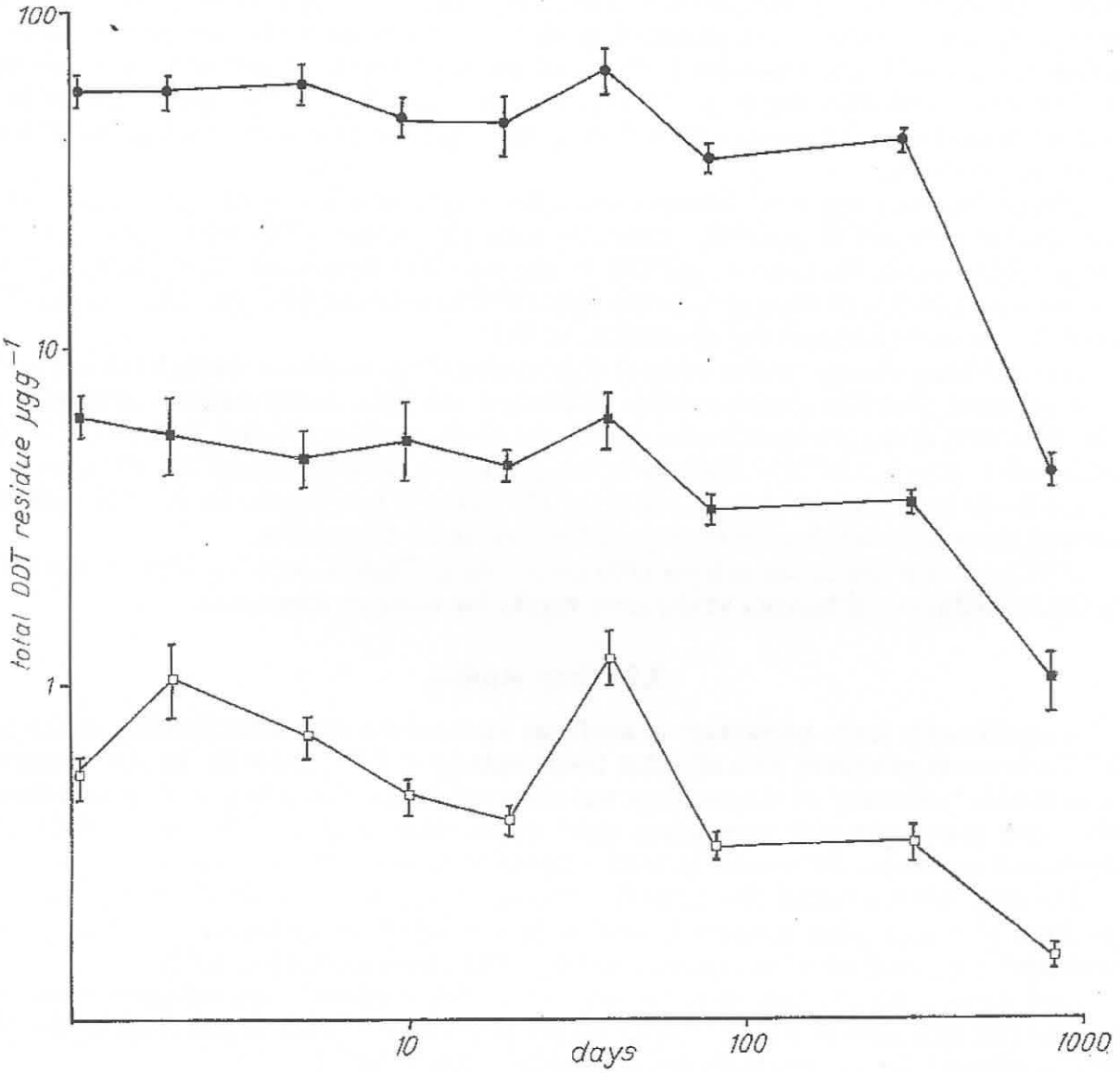

Fig. 1. Total DDT residue over the 0—300 mm soil horizon from August 1974 to November 1976 in low (□—□), medium (■—■) and high (●—●) DDT treatments. Standard errors are indicated.

3. Results

3.1. Pesticide studies

Considerable within plot variation in the total detectable residue levels was apparent from the detailed samples taken from one replicate of each treatment at the beginning of the experiment. In the high DDT plot the mean residue level in the 0—150 mm soil horizon was 66.7 $\mu g\ g^{-1}$ with a range from 20.6 — 108.8 $\mu g\ g^{-1}$. In the medium DDT plot the mean level was 8.7 $\mu g\ g^{-1}$, range 2.3 — 31.3 $\mu g\ g^{-1}$ and the low DDT plot 0.7 $\mu g\ g^{-1}$, range 0.3—1.2 $\mu g\ g^{-1}$. This variation was attributable to the method of pesticide application. Further, the DDT was not evenly distributed through the 0—150 mm horizon but over 80% of the applied pesticide was concentrated in the top 0—50 mm.

Total residue levels in the 0—300 mm soil horizon determined from the bulked samples taken over the first 80 days of the experiment and in subsequent years are shown in Fig. 1. The initial samples approximated to the expected concentrations of 0.5, 5.0 and 50 $\mu g\ g^{-1}$. A significant reduction in the total DDT residues over the first 80 days occurred only in the medium DDT treatment ($p < 0.05$). Residue levels in all treatments at 40 days were higher than the initial samples and it is possible that contamination had occurred during the extraction process. In all treatments there was no significant change in the total residue

level between the 80 day sample (November 1974) and the sample taken in July 1975 (310 days) although the plots were ploughed in May and June. After this the plots reverted to fallow and a significant reduction in the total residue level was observed in all treatments in November 1976 (800 days) ($p < 0.01$). By this time 28% of the applied pesticide remained in the low DDT treatment, and 16% and 7% in the medium and high DDT treatments respectively.

Differences were apparent between the three treatments in the rate of degradation of the applied pesticide to ppDDE. After 800 days (November 1976) 55% ($0.09\,\mu g\,g^{-1}$) of the pesticide was in the form of ppDDE in the low DDT treatment, 33% ($0.32\,\mu g\,g^{-1}$) in the medium and 5% ($0.23\,\mu g\,g^{-1}$) in the high DDT treatments. The proportion of ppDDT : opDDT was fairly constant for all samples at 4 : 1.

No significant changes in the vertical distribution of the pesticide through the soil profile were apparent from the three occasions of detailed sampling. In the medium and high DDT plots 91—96% of the total residue occurred in the 0—50 mm layer, 3—8% in the 50—100 mm layer and 1—8% in the 100—150 mm layer. In the low DDT plots only 79—85% occurred in the 0—50 mm horizon and 11—16% at the 50—100 mm depth. In the 150—300 mm horizon the residue levels were 0—6% of the total in all treatments.

DDT residue levels in the cowpea crop are shown in Table 1. together with residue levels in the 0—150 mm soil horizon at the time vegetation samples were taken.

3.2. Crop studies

A significantly lower percentage of seedlings emerged six days after planting in the high DDT treatment compared with all other treatments ($p < 0.05$; Table 2). In this treatment considerable 'yellowing' of the seedlings was observed during the early growth period though when five plants per plot were taken eight weeks after planting, dried and weighed, no significant treatment differences in total vegetative production were apparent.

The crop was harvested 10—12 weeks after planting, the beans dried and threshed and the total plot seed yield measured. Seed yield was significantly higher in the high DDT treatment compared with the control and other DDT treatments ($p < 0.01$).

Seed damage assessments were carried out on 200 randomly selected seeds from each plot harvest and showed a significantly higher percentage of undamaged seeds in the high DDT treatment than in the other treatments ($p < 0.01$; Table 2).

3.3. Microarthropod populations

3.3.0. General remarks

Collembola and Acari were the most abundant groups extracted from soil cores, accounting for approximately 90% of the total fauna. Other groups of microfauna extracted included Diplura, Protura, pterygote Insecta (mainly represented by coleopteran and dipteran larvae), Chelonethida, Araneida, Myriapoda and Oligochaeta (predominantly Enchytraeidae) though all groups were present in low numbers, none exceeding 3% of the total fauna. Dipluran and proturan populations were significantly reduced in the high DDT treatment, the latter also being reduced in the medium DDT treatment ($p < 0.01$). The responses of Collembola and Acari to DDT treatment over the three years are shown in Table 3 and are described separately in the following section.

3.3.1. Collembola

Data for the collembolan families Poduridae, Onychiuridae, Entomobryidae, Isotomidae and Sminthuridae were considered collectively because of their similarities in terms of feeding behaviour (Hale 1967) and responses to DDT treatment. In the first sample, taken 15 days after soil treatment, collembolan populations were very low in the control, low and medium DDT treatments and none was observed in soil from the high DDT treatment.

Table 1. Total* DDT residue levels in cowpea and soil 80 days after soil treatment and planting ($\mu g\ g^{-1} \pm$ standard error)

	Low DDT	Medium DDT	High DDT
Root	2.1 ± 0.4	15.9 ± 2.7	97.1 ± 24.4
Stem	0.4 ± 0.2	2.1 ± 0.5	16.7 ± 7.9
Leaf	0.6 ± 0.2	1.7 ± 0.3	6.8 ± 0.6
Husk	0.7 ± 0.3	0.8 ± 0.2	2.6 ± 0.5
Bean	**	**	**
Soil 0—150 mm	0.28 ± 0.02	3.0 ± 0.2	33.9 ± 2.5

* ppDDT op DDT ** trace, less than $0 \cdot 4\ \mu g\ g^{-1}$

Table 2. Cowpea crop studies (± standard error)

	Control	Low DDT	Medium DDT	High DDT
% Seedling emergence	91.7 ± 2.8a	89.4 ± 4.4a	83.6 ± 4.5a	65.0 ± 6.2b
Vegetative production dry weight kg ha^{-1}	875 ± 150a	917 ± 242a	975 ± 108a	975 ± 158a
Seed yield kg ha^{-1}	70.0 ± 6.5a	79.9 ± 14.2a	95.5 ± 30.1a	186.7 ± 27.7b
% Undamaged seed	55.1 ± 3.0a	59.4 ± 1.6a	61.0 ± 1.7a	70.3 ± 3.8b

Values within a row followed by the same letter are not significantly different ($p < 0 \cdot 05$).

Table 3. Population levels of Collembola and Acari assessed from soil cores (mean $\times 10^3\ m^{-2} \pm$ standard error)

		Control	Low DDT	Medium DDT	High DDT
Collembola					
September 1974	0— 50 mm	1.5 ab	2.9 a	1.1 ab	0 b
August 1975	0— 50 mm	11.3 a	*	23.9 b	1.5 c
August 1976	0— 50 mm	19.1 a	19.4 a	33.6 b	47.2 b
August 1975	50—100 mm	5.6 a	*	19.0 b	0.6 c
August 1976	50—100 mm	3.5 a	4.0 ab	6.5 ab	7.7 b
Prostigmata					
September 1974	0— 50 mm	3.7 a	1.4 ab	1.2 ab	0 b
August 1975	0— 50 mm	22.2 a	*	11.5 b	0.8 c
August 1976	0— 50 mm	11.3 a	16.1 a	12.8 a	9.8 a
August 1975	50—100 mm	6.4 a	*	3.5 b	0.1 c
August 1976	50—100 mm	7.8 a	6.5 ac	3.7 bc	2.0 b
Mesostigmata					
September 1974	0— 50 mm	0.4 a	0.6 a	0.3 a	0 a
August 1975	0— 50 mm	2.7 a	*	0.1 b	0 b
August 1976	0— 50 mm	12.7 a	16.5 a	11.1 a	6.8 b
August 1975	50—100 mm	1.2a	*	0.2 a	0 a
August 1976	50—100 mm	6.9 a	4.6 a	4.7 a	2.0 b
Cryptostigmata					
September 1974	0— 50 mm	2.8 a	3.1 a	1.4 a	0 b
August 1975	0— 50 mm	22.1 a	*	13.1 b	0.3 c
August 1976	0— 50 mm	14.7 a	14.5 a	14.7 a	11.3 a
August 1975	50—100 mm	8.1 a	*	11.6 a	2.4 b
August 1976	50—100 mm	3.8 a	3.2 a	3.2 a	1.6 a

Values within a row followed by the same letter are not significantly different ($p < 0.05$). * no data.

Table 4. Mean earthworm casting activity $m^{-2}\ day^{-1}$ over 11 weeks (September to November)

	Control	Low DDT	Medium DDT	High DDT
Hyperiodrilus				
Number of casts	1.23 a	0.67 b	0.62 b	0.19 c
Dry weight of casts	1.13 a	0.52 b	0.81 b	0.18 c
Eudrilus				
Number of casts	0.95 a	0.94 a	0.10 b	0 c

Values within a row followed by the same letter are not significantly different ($p < 0.05$).

By August 1975 the populations had recovered and numbers in the medium DDT treatment exceeded those in the control ($p < 0.01$). The high DDT treatment still contained very low populations of Collembola. A year later high populations were present in both medium and high DDT treatments, significantly higher than in the control and low DDT treatments ($p < 0.05$). The population in the low DDT treatment appeared unaffected and did not differ from that in the control.

3.3.2. Acari

The Acari extracted from the cores included Prostigmata, Mesostigmata and Cryptostigmata. As with the Collembola, populations of all three groups of Acari were very low in 1974 and none was found in the high DDT treatment. In 1975 the populations of Prostigmata and Cryptostigmata had recovered in the control plots and were significantly higher than in the medium DDT treatment ($p < 0.05$) which in turn contained more of both groups than the high DDT treatment ($p < 0.05$). Mesostigmata populations remained low in 1975 though the population in control plots was significantly higher than in all DDT treatments ($p < 0.01$). By 1976 populations of Prostigmata and Cryptostigmata were the same in all treatments, though Mesostigmata were still significantly reduced in the high DDT treatment ($p < 0.05$).

3.4. Earthworm casting activity

The mean casting activities of *Hyperiodrilus* and *Eudrilus* over the first eleven weeks of the experiment are shown in Table 4. For *Hyperiodrilus* both the number and dry weight of casts produced were significantly higher in the control than in all DDT treatments. The casting rates of *Eudrilus* in the control and low DDT treatments were similar and both significantly higher than the medium and high DDT treatments ($p < 0.01$). The casting activity of both species fluctuated throughout the experiment in direct relation to soil moisture content, being reduced to zero in all treatments after 13 weeks due to the onset of the dry season.

3.5. Buried litter studies

The regression slopes for the rate of decomposition of buried leaf litter in the four treatments are shown on Fig. 2, the regression coefficients being —0.0053, —0.0047, —0.0037 and —0 · 0036 for control, low, medium and high DDT treatments respectively. Decomposition was most rapid in the control treatment and was reduced even by low levels of DDT ($p < 0.05$). No difference was apparent between medium and high DDT treatments, decomposition rates in both cases being significantly lower than in other treatments ($p < 0.01$). A faster apparent rate of decomposition was observed in all treatments over the first ten days when 10—15 % of the initial weight was lost due to leaching.

Collembola and Acari were the most abundant microarthropods extracted from the buried litter, accounting for 90—100 % of the fauna. The numbers of Collembola, Prostigmata, Mesostigmata and Cryptostigmata extracted on each occasion are shown in Figs. 3 and 4. The level of colonisation of the buried litter by Collembola was similar in control, low and medium DDT treatments but was significantly lower in the high DDT treatment ($p < 0.01$). In all treatments the populations reached a peak after 40 days.

The Prostigmata showed a similar pattern of invasion in the control and low DDT treatments, reaching a peak after ten days. Significantly fewer Prostigmata were present in the medium and high DDT treatments ($p < 0.05$). The Mesostigmata populations in the control, low and medium DDT treatments were highest after ten days when the population in the latter treatment exceeded that for all others ($p < 0.05$). The population of Mesostigmata in the high DDT treatment was greatest after 40 days, when there were significantly more extracted than from buried litter in the control plots.

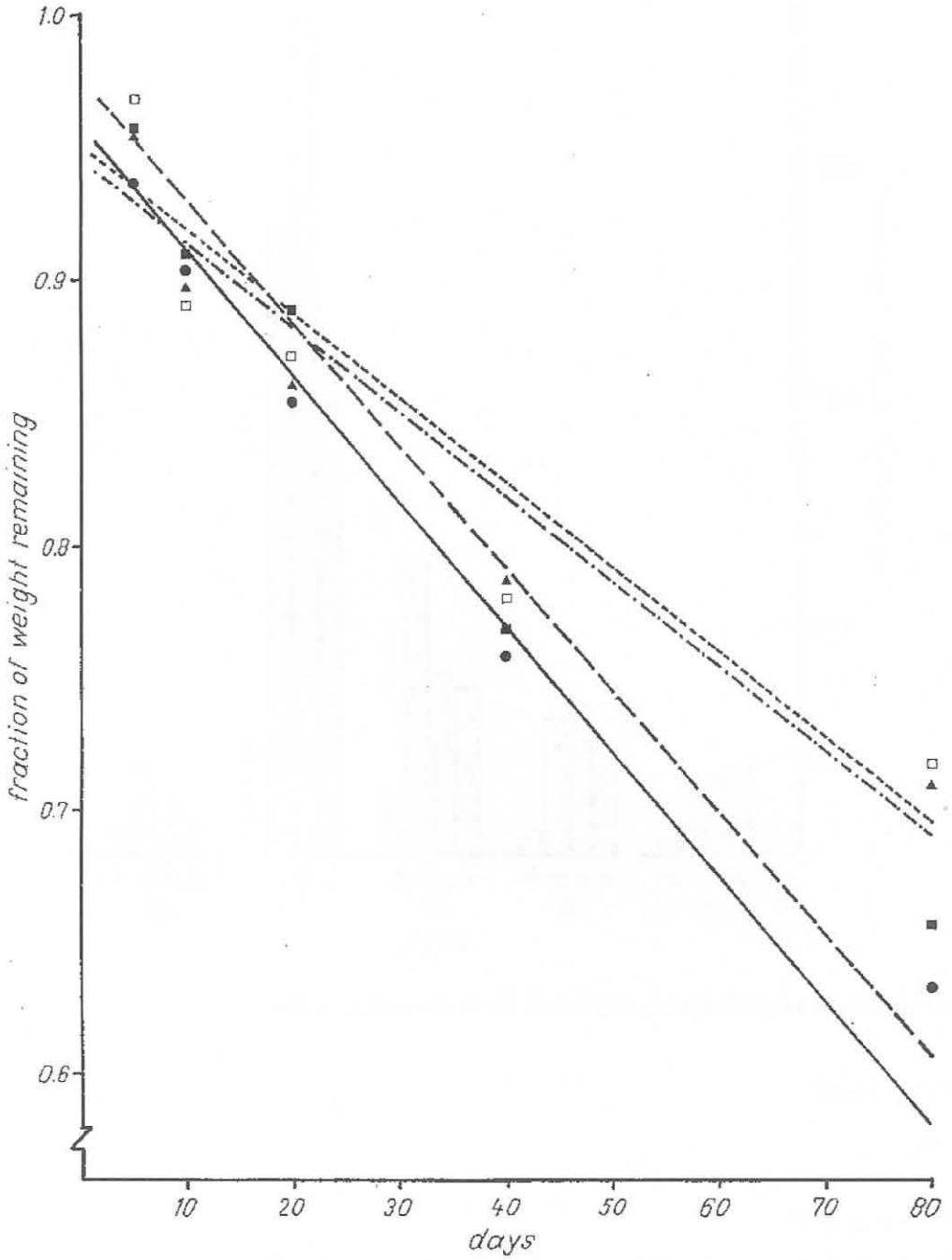

Fig. 2. Regression slopes for the rate of decomposition of buried leaf litter and treatment means for the five sampling occasions. ——●— control; —— ■ low; ·—·—· ▲ medium; ------ □ high DDT treatments.

Table 5. Mycelial counts from the buried leaf litter (m mycelium × 10^3 g^{-1} leaf material ± standard error)

Time leaf material buried (days)	Control	Low DDT	Medium DDT	High DDT
5	2.8 ± 0.4 a	5.2 ± 0.7 a	2.1 ± 0.2 a	2.0 ± 0·2 a
40	17.5 ± 0.6 a	28.4 ± 1.2 b	18.8 ± 0.9 a	12.2 ± 1.0 c
80	16.3 ± 2.8 a	19.5 ± 0.7 a	9.2 ± 0.9 b	5.9 ± 0.4 b

Values within a row followed by the same letter are not significantly different ($p < 0 \cdot 05$).

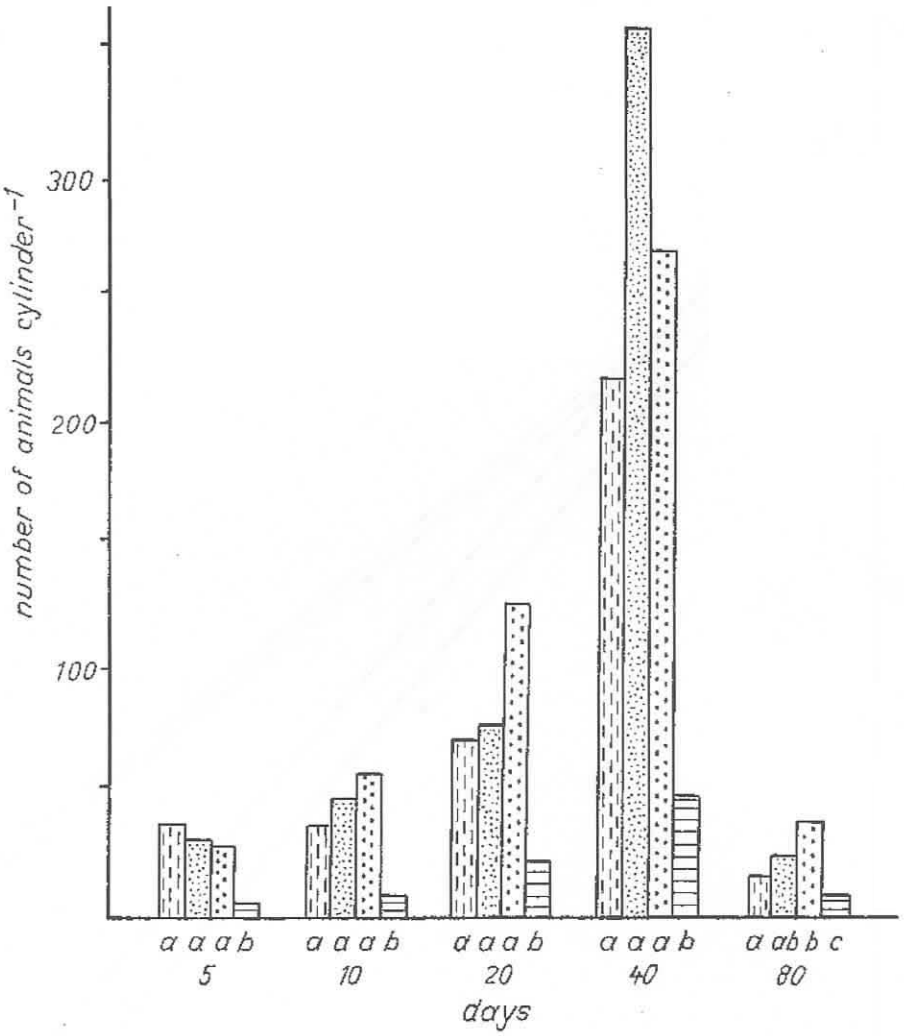

Fig. 3. Mean numbers of Collembola extracted from the buried litter;

control and

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high DDT treatments. Columns within a block having the same letter are not significantly different ($p < 0.05$).

The Cryptostigmata showed a slower rate of colonisation of the buried litter than other groups of microarthropods in the control, low and medium DDT plots. No differences were observed between populations in these three treatments and the levels of Cryptostigmata increased progressively from 5 to 80 days. On all occasions the numbers of Cryptostigmata extracted from the buried litter in the high DDT treatment were very low and no population buildup was observed.

Mycelial biomass on the buried leaf material increased from the same level for all treatments after 5 days to a peak after 40 days and declined after 80 days. Significantly more mycelium was present on litter from the low DDT treatment than other treatments at day 40 and more mycelium was present in the medium DDT and control treatments than high DDT treatment ($p < 0.01$). By day 80 the mycelial biomass on litter buried in control and low DDT treatments were similar, being significantly higher than in the medium and high DDT treatments ($p < 0.1$; Table 5).

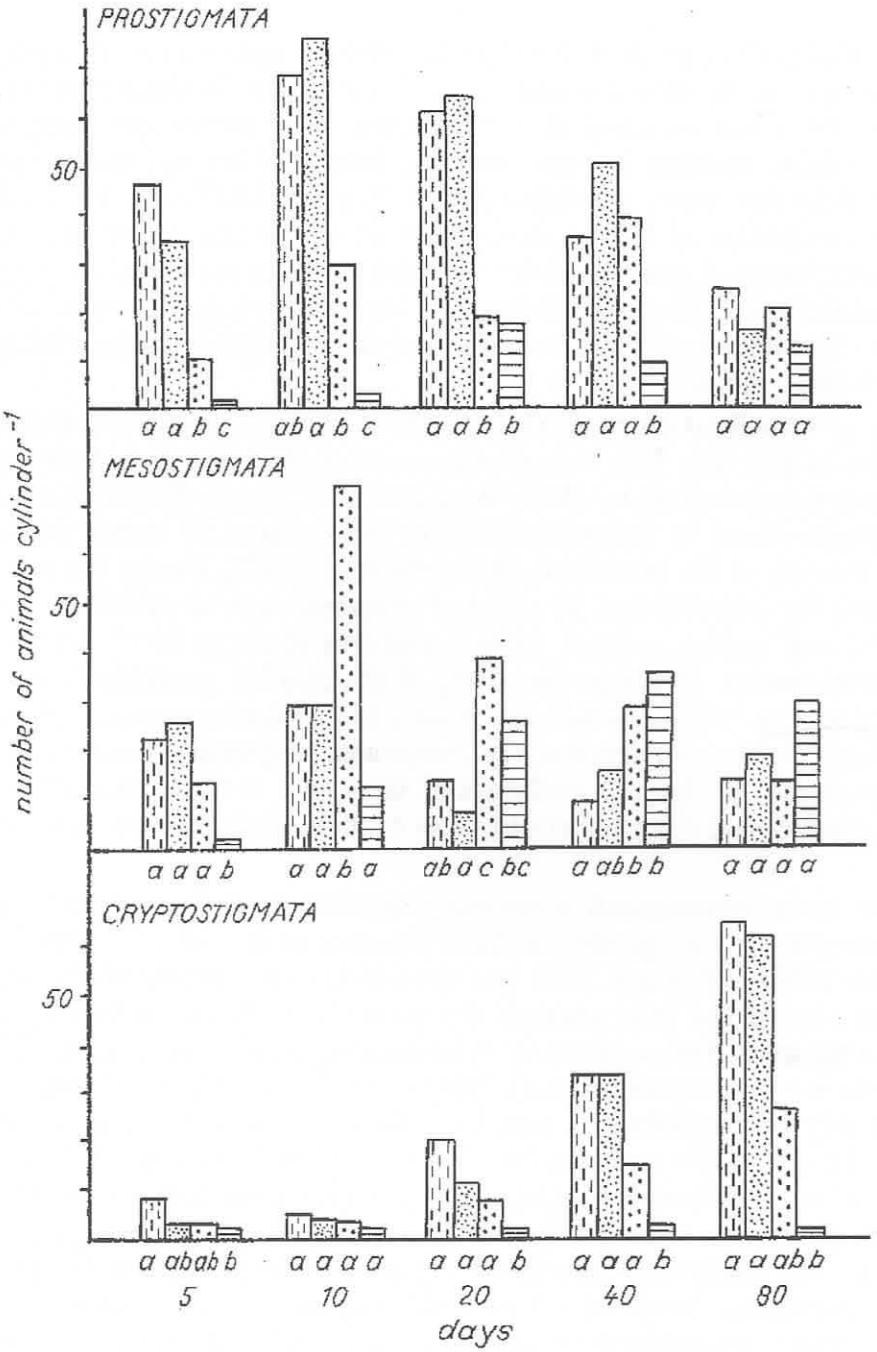

Fig. 4. Mean numbers of Prostigmata, Mesostigmata and Cryptostigmata extracted from the buried litter;

control and

low,

medium and

high DDT treatments. Columns within a block having the same letter are not significantly different ($p < 0 \cdot 05$).

4. Discussion

The persistence of organochlorine pesticides in soil is influenced by climatic factors and is correlated positively with organic matter and clay content (EDWARDS et al. 1957). Heavier clay soils generally retain pesticides longer than lighter, sandy soils. The soils at the experimental site belong to the Gambari series (MOORMAN et al. 1975) and are characterised as sandy loams with low organic matter content. They thus have a relatively low capacity for the retention of DDT.

EDWARDS (1966) estimated that the time for 95 % disappearance of DDT from the soil in temperate regions was 4—30 years with a mean of 10 years. In the present study 72—93 % disappearance of DDT had occurred after 26 months. The mechanisms likely to be involved in the loss of pesticide residues include leaching, volatilisation and biological degradation. Due to its extremely low water solubility ($2\times10^{-4}\mu g\ g^{-1}$) DDT does not leach extensively even under the conditions of high rainfall encountered in the humid tropics. Downward movement by infiltration of small particles to which residues are adsorbed is another mechanism for the redistribution of pesticide through the soil profile. However, after 26 months no redistribution had occurred, more than 80 % of the remaining residues being still located in the 0—50 mm soil horizon.

Higher rates of volatilisation of DDT from wet soils have been recorded than would be expected in view of the very low vapour pressure (1×10^{-7} mm Hg at 20 °C) of the DDT molecule (HARRIS & LICHTENSTEIN 1961; BOWMAN et al. 1965). Recent work suggests that this is due to displacement of the pesticide from soil surfaces by water, resulting in an increased vapour density of the insecticide (SPENCER et al. 1973). During the period of cultivation the conditions for pesticide loss by physical processes such as volatilisation were optimal with the exposed soil surface subject to temperatures of up to 50 °C, high rates of water loss and intense radiation. Between 38—51 % of the applied pesticide disappeared during the first growing season, when the soil had a very low moisture content. During the subsequent 17 months of fallow regeneration the continuous vegetation cover reduced air movement and temperature at the soil surface and biological activity increased. Under these conditions biological rather than physical routes of degradation were probably more important.

Most workers have investigated microbial degradation of DDT under anaerobic conditions, where the principal by-product is TDE (CHACKO et al. 1966; GUENZI & BEARD 1968; KO & LOCKWOOD 1968). Although TDE was detected in the present study it represented a very small proportion of the total residue, the major breakdown product being DDE, suggesting the principal degradation pathway to be aerobic. Similar conversion of DDT to DDE in soils was shown by LICHTENSTEIN et al. (1971) and YULE (1973). The conversion of DDT to DDE is probably accomplished in part by microflora, since a range of microorganisms has been shown to effect this reaction (see KAUFMAN 1974), though DDT can also be degraded to DDE some soil microarthropods. This has been demonstrated for the collembolan *Folsomia candida* (BUTCHER et al. 1969) and the astigmatid mite *Caloglyphus krameri* (BUTCHER et al. 1971). The analytical date showed that the rate of conversion of DDT to DDE was slower with increasing levels of soil contamination and it is possible that this was associated with reduced populations of soil microarthropods in the high DDT treatment. Further the rate of conversion of DDT to DDE was greater during the fallow period when soil populations were increasing. However, the situation is complicated by a lack of information on the potential of a given soil population to degrade DDT and limited knowledge of the mobility of DDE in soil.

DDT residues in cowpea vegetation samples could have been incorporated via the stomata and root systems or, for the aerial parts of the plant, could be surface deposits resulting from condensation of residues volatilised from the soil. The residues levels in root tissues for plants grown in the high DDT treatment were higher than could have arisen from contamination by soil particles adhering to the roots and some pesticide uptake must have occurred. The amount of DDT present 'in or on' the plant in this treatment was sufficient to afford some protection from the major cowpea pests, the pod borer *Maruca testulalis* GEYER and the pod suckers *Acanthomia horrida* GERM., *A. tomentosicollis* STAL and *Riptortus dentipes* FAB. This was reflected in the lower levels of seed damage and higher seed yield. Incorporation of pesticide into the soil may have reduced populations of other cowpea pests having a soil inhabiting phase in their life-cycle, thus contributing to the increased yields. The larvae and pupae of the leaf-feeding beetle *Ootheca mutabilis* SAHLB. are soil dwelling, as are the pupae of the foliage thrip *Sericothrips occipitalis* HD. and the flower thrip *Megaluro-*

thrips sjostedti TRYB., though lateral and aerial reinvasion by these species would have been fairly rapid due to the small size of the plots and the proximity of untreated plots and secondary thicket.

The overall results show a marked effect of DDT incorporation on soil microarthropod populations. Very low numbers were present in 1974 in all treatments associated with clearing, cultivation and soil disturbance during pesticide application though it is noteworthy that only in the high DDT treatm entwere microarthropods completely absent. By thefollowing year pesticide effects were apparent. Collembolan populations were maintained at a low level due to the direct toxic effect of the pesticide in the high DDT treatment but in the medium DDT treatment increased above those in the control. This phenomenon is probably associated with reduced predator pressure due to the difference in DDT tolerance levels of Collembola and their major predators the mesostigmatid mites, which were eliminated in this treatment. This effect has frequently been observed under temperate conditions (EDWARDS 1965b; EDWARDS & DENNIS 1960; EDWARDS et al. 1967; SHEALS 1956; BUND 1965). Cryptostigmatid mites were absent from the high DDT treatment and were significantly reduced in the medium and high DDT treatments in 1975. This may be of particular importance in litter breakdown since many members of this group are macrophytic (WALLWORK 1958; WOOLLEY 1960). LUXTON (1972) showed that some possess cellulase, pectinase and xylase which enable them to digest the complex polysaccharides of higher plants. From 1975 to 1976 populations of microarthropods increased in all treatments, probably in association with the more favourable habitat created by litter fall from the regenerating secondary thicket and reduction of pesticide residues in the soil of treated plots.

Many studies have been carried out in temperate situations on the effects of DDT on earthworm populations (EDWARDS & DENNIS 1960; EDWARDS 1965a, b; THOMPSON 1970) and results indicate that at normal rates of DDT application earthworm populations are unaffected. In the present study earthworm population estimates could not be made without serious disruption of the plots because of their small size. However, DDT effects on casting activity were apparent. That of *Hyperiodrilus* was affected by even low levels of soil contamination. Casting activity of *Eudrilus* was unaffected by low levels but was reduced in the medium DDT treatment. Earthworm activity results in increased aeration through burrowing and extensive mixing of sub- and topsoils which improves water retention. A reduction in casting activity could therefore have serious consequences for soil structure. Further, chemical analysis of earthworm casts from similar soils revealed a twofold increase in calcium and nitrogen, a threefold increase in organic carbon and potassium and a fivefold increase in phosphorus compared with the parent soils (COOK et al. in prep.). In temperate soils earthworms play an important role in the cycling of organic matter by the initial fragmentation and incorporation of litter into the soil (EDWARDS & HEATH 1963; RAW 1962) though studies in Nigeria by MADGE (1965) suggest that earthworms are less important in this respect than temperate species because they do not buryleaf material but feed on organic matter already incorporated into the soil. Populations under bush fallow may contribute to the initial incorporation of litter by their extensive casting activity, though under cultivated conditions this is so reduced that it is not a major factor.

The rate of decomposition of buried leaf material in mesh cylinders decreased significantly with higher levels of soil contamination. This decrease occurred despite stimulation of the activity of cellulolytic microorganisms in the high DDT treatment (IITA 1974) and underlines the importance of the microfauna in leaf decomposition, an observation supported by studies in which decomposition was reduced when microarthropods were excluded using fine mesh bags (SWIFT et al. in prep.).

Interpretation of the microarthropod data from the buried litter is complex. The cylinders provided a very artificial but highly favourable habitat which was rapidly invaded by microfauna. Initial colonisation would have been dependant on the population levels in the surrounding soil and thus likely to differ in the four treatments from the outset. The lower populations of Collembola, Prostigmata and Mesostigmata in the high DDT treatment

after five days were therefore probably due to a direct toxicity effect of the DDT. These results reflect the soil population assessments from soil cores taken 14 days after soil treatment.

In addition to colonisation by fauna, the leaf material also provided a substrate for the development of fungi. After 40 days fungal biomass was shown to be significantly higher in the low DDT treatment than the medium DDT and control treatments and significantly lower in the high DDT treatment. Collembolan populations within the cylinders and fungal biomass appeared to be closely related. This was probably due to the fact that the method used for measuring fungal biomass did not give a direct measure of mycelial standing crop but included mycelial fragments incorporated into animal faeces together with dead fungal material. Thus cylinders supporting large populations of fungivorous microarthropods would tend to give higher counts of fungal biomass due to an increased rate of mycelial turnover associated with microarthropod grazing. Mycelial standing crop may not, however, have differed from cylinders with lower microarthropod populations.

Populations of Collembola, Prostigmata and Cryptostigmata within the cylinders were significantly lower in the high DDT treatment due to either a direct DDT toxicity effect or a lower initial soil population and thus lower colonisation potential. The responses of the Mesostigmata populations are difficult to interpret. At the time the cylinders were buried Mesostigmata were absent from the high DDT plot soils yet after 40 days populations within the cylinders in this treatment were significantly higher than in the control. It is possible that even with a very low invasion level, conditions within the cylinders were so favourable as to support rapid population buildup with little movement out of the cylinders into the heavily contaminated plot soils. Mesostigmata formed a much greater proportion of the total microfauna in the buried litter compared with soil populations; up to 20, 27, 45 and 60 % for control and low, medium and high DDT treatments, compared with 5—8 % in soil samples.

The microarthropod data from the buried litter suggests that the Prostigmata and Cryptostigmata were primarily responsible for the litter breakdown since, unlike the Collembola, both groups were present in lower numbers in those treatments having the lowest rates of decomposition.

Thus a range of studies has shown that direct incorporation of DDT into the soil has considerable effects on both soil populations and soil processes. Usual methods of foliar application of DDT would, however, rarely result in soil contamination reaching that of the medium DDT treatment and levels as high as those in the high DDT treatment have been recorded only in orchard soils (EDWARDS 1973).

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6. Summary · Zusammenfassung

DDT was applied directly to the soil over a range of concentrations prior to cultivation with cowpea *Vigna unguiculata* (L.) WALP and its effect on soil microarthropods and microflora, earthworm casting activity and the rate of decomposition of organic matter were investigated.

Initially, microarthropod populations were low in all treatments due to the effects of bush clearing and cultivation but after one year effects on Collembola were apparent, these being reduced in the highest DDT treatment and increased at lower concentrations compared with control plots as a result of elimination of their major predators, the mesostigmatid mites. Cryptostigmatid mites, the dominant detritivores of the microfauna were reduced by high levels of DDT in the soil. Earthworm casting activity and the rate of decomposition of buried leaf litter were reduced even by the lowest DDT concentration.

Die Wirkungen einer DDT-Behandlung auf Lebensvorgänge in einem kultivierten Forstboden in den subhumiden Tropen

Vor dem Anbau der „Kuherbse" *Vigna unguiculata* (L.) WALP [Fabaceae] wurde DDT in verschiedenen Konzentrationen dem Boden direkt zugesetzt. Die Wirkung dieser Maßnahme auf Boden-Mikroarthropoden und Mikroflora, die Losungsproduktion von Regenwürmern und die Raten beim Abbau von organischen Substanzen wurden untersucht.

Anfänglich waren die Besatzdichten der Mikroarthropoden infolge des Kahlschlags und der Kultivierung des Bodens in allen Versuchsgliedern gering, doch nach einem Jahr waren die Wirkungen auf Collembolen augenscheinlich. Die Collembolen wurden in den Parzellen mit den höchsten DDT-Konzentrationen dezimiert und ihre Anzahl stieg in den Parzellen mit geringeren Konzentrationen an, im Vergleich zur Besatzdichte in den unbehandelten Kontrollparzellen, infolge der Elimination der wichtigsten Prädatoren, der mesostigmatischen Milben. Cryptostigmatische Milben, die dominierenden Detritivoren der Mikrofauna, wurden durch höhere DDT-Konzentrationen im Boden (ebenfalls) dezimiert. Die Losungsproduktion durch die Regenwürmer sowie die Abbauraten der im Boden eingegrabenen Blattstreu wurden aber gerade durch die niedrigsten DDT-Konzentrationen vermindert.

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